Ocean Monitoring, Coastal Studies and Remote Sensing

John Orcutt
Cecil and Ida Green Institute of Geophysics and Planetary Physics
University of California, San Diego
La Jolla, California 92093-0225
telephone: (858) 534-2887 fax: (858) 822-3372 e-mail: jorcutt@ucsd.edu

Brad Werner
Complex Systems Laboratory
Cecil and Ida Green Institute of Geophysics and Planetary Physics
University of California, San Diego
La Jolla, California 92093-0225
telephone: (858) 534-0583 fax: (858) 534-9873 e-mail: bwerner@ucsd.edu

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LONG-TERM GOALS

The long-term goal of this research is to develop and test predictive models for nearshore processes. Initial development and testing of models is to be accomplished through monitoring over a broad range of spatial (both horizontal and vertical) and temporal scales. Model development takes place within the framework of the nearshore as a hierarchical complex system, wherein, at discretely ordered space and time scales, a small number of variables emerge as the dominant influences on the dynamics of this nonlinear, open system and the interactions between these variables give rise to complex, emergent behavior.

OBJECTIVES

The specific objectives of this research project are (i) to identify the dominant variables and processes operative in the nearshore; (ii) to formulate and develop predictive, hierarchical complex systems models for nearshore processes and features, including sand bars, megaripples, breaking waves, infragravity wave generation, surf zone currents, and swash zone flow and morphology; (iii) to monitor (on time scales ranging from seconds to years and spatial scales ranging from meters to a kilometer) nearshore bathymetric, volumetric and hydrodynamical patterns; (iv) to relate complex systems models to measurements acquired through remote sensing; and (v) to propose and design new field experiments capable of refuting complex systems and competing models.

APPROACH

Computer simulations, theory and field observation, experimentation and monitoring are combined to formulate, develop, test and refine models for nearshore hydrodynamics and bathymetry.

The underlying assumption of this research is that models for nearshore processes should reflect their nonlinear, open and dissipative nature, which selects and orders variables and processes through collective self-organization. One form of variable selection in the nearshore and many other nonlinear systems is spatial localization of dynamics, owing to collective nonlinear interactions. Examples of such localization include breaking wave fronts, offshore currents localized into rips and focused bathymetric

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change at shorelines or sand bars. In addition, variables at different temporal scales do not interact symmetrically. This well-studied property of nonlinear, dissipative systems stems from the tendency of fast temporal scale motion to be dissipated over longer time periods. For example, the fast, but dissipative motion of a sand grain in a more sluggish offshore migrating sand bar is slaved by or follows the bar.

The traditional Reductionist Approach (fundamental physics/equations) fails for natural systems such as the nearshore because of a lack of defensible criteria for selecting dynamical variables. The necessity that all dynamics stems from the fundamental scales and processes in Reductionism conflicts with the asymmetrical interactions between scales for nonlinear, dissipative systems, with the larger, longer scales being dominant. Universalist approaches (using the simplest system in a class of systems sharing common behaviors to model the entire class) fail because the simplifying assumptions underlying Universalist models necessarily imply an inability to treat the variability and complexity inherent in the natural environment (external to the system being studied).

A new, hierarchical modeling methodology is meant to address these criticisms of Reductionism and Universality. It can be summarized with the following four steps:

(i) delineate the boundaries of the open system;
(ii) identify and temporally order dynamical variables of the system and variables in the external environment affecting system dynamics;
(iii) at each level in this temporal hierarchy, encapsulate the dynamics of faster variables into minimal rules that relate the evolution of variables at this level to each other and to the external environment;
(iv) formulate models at each level and derive testable predictions of the models.
(v) test the theoretical consistency of the modeling hierarchy by comparing predictions for a phenomenon from models at two different levels (thereby enhancing the testability of the models).

This methodology is distinguished from Reductionism and Universality primarily by modeling phenomena at their intrinsic time scales. For example, to model motion of a sand bar, the variables appearing in the model describe that motion (e.g., sand bar position and height), not positions of sand grains, nor the flux of sand nor water motions over the bar, all of which have much smaller intrinsic time scales and are expected to be slaved to the motion of the bar.

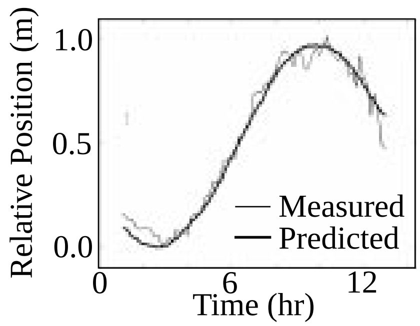
WORK COMPLETED

(i) An argument for simple models having better predictive capacity than traditional Reductionist models was formulated; (ii) a surf zone sand bed imaging technique was improved and further tested; (iii) monitoring of megaripple occurrence and dynamics at Scripps Beach was extended and the results analyzed; (iv) crescentic sand bar formation was modeled with two different approaches; (v) a technique for detecting and monitoring surf zone wave crest dynamics was extended and tested; and (vi) instrumentation for recording high bandwidth ('chirp') - to 16 kHz - seismoacoustic data was developed and tested.

RESULTS

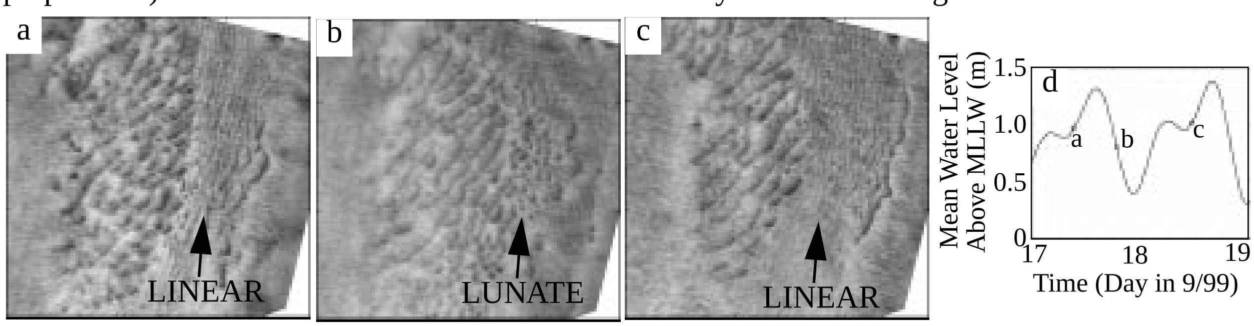
Simple models, those that omit many of the details relating to fundamental variables and processes, often are portrayed as a means of obtaining insight into how systems work, but not as a means to obtain accurate predictions, a task that is said to require more complete, traditional Reductionist codes. An argument has been constructed that simple models employing variables with intrinsic time scale of the

order of the time scale of the phenomenon of interest offer better predictive capabilities than models employing variables whose evolution is governed by fundamental processes. Elements of this argument include: (i) slow, emergent variables generally slave fast variables, so that emergent dynamics are not determined by fundamental processes; (ii) predictions made with models using fewer variables with slower characteristic time scales are intrinsically more accurate than predictions made using more variables with faster time scales; and (iii) incorporating the worst nonlinearities of a system, those that connect disparate time scales, into successive definitions of emergent variables at higher levels of a hierarchy can filter out much of the inherent fast-scale unpredictability of nonlinear systems (Werner, 2000).

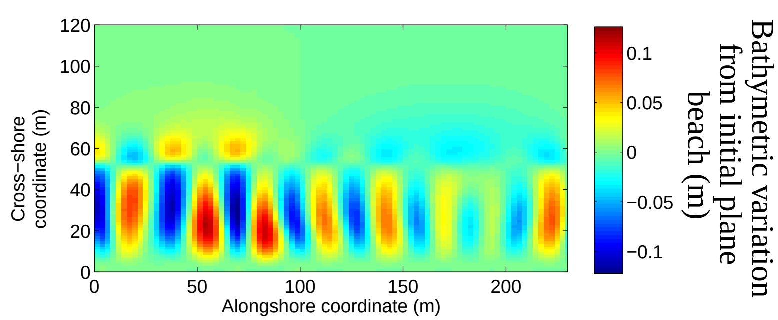


A surf zone sand bed imaging technique was improved for the purpose of extracting accurate positions of bedform crestlines and other bed features. The technique employs a threshold filter to video frames to retain pixels that might represent parts of the image where the sand bed is visible. These retained pixels are averaged over a time varying from 2-10 minutes; the resulting images are enhanced to bring out features such as megaripple crestlines. Improvements to the technique include a correction for refraction, which can cause significant apparent velocities of bed features as tide level changes (see above to right for comparison of predicted and measured position of a fixed instrument near the bed: Clarke and Werner, 2000) and a lighting model, which permits assessment of the visibility of the bed under varying conditions.

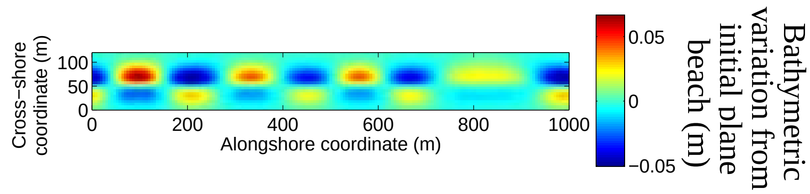
Continuous monitoring of bed features during daylight hours using this imaging technique has permitted documentation of common dynamical behaviors of the surf zone sand bed, including cyclical transitions between linear and lunate megaripples (below: Clarke and Werner, 2000; in preparation). Current efforts are focused on further analysis and modeling of these transitions.



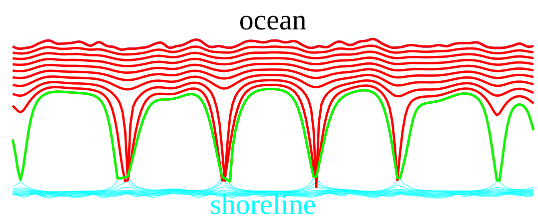
The formation and development of transverse and crescentic sand bars and the transitions between bar types are being investigated with two distinct models: a nonlinear numerical model and a simple model employing emergent variables and processes. In the former model (Coco et al., in preparation), most suitable for modeling formation of bathymetric features, bathymetric change is



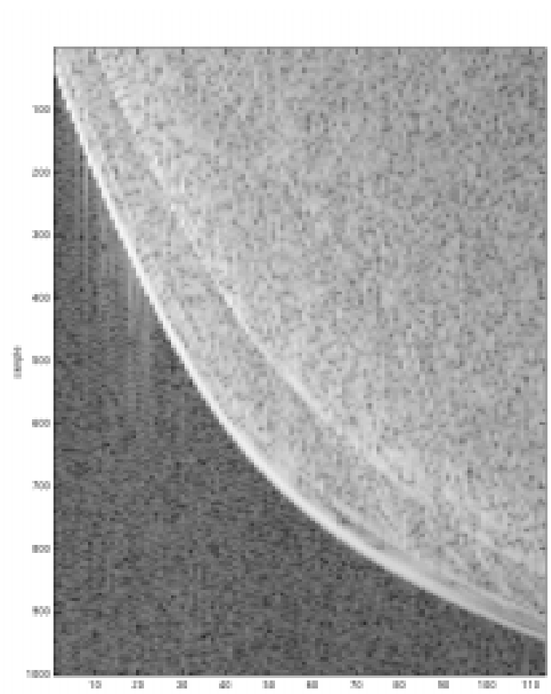
calculated using time-averaged nonlinear shallow water equations and a simplified sediment transport parameterization, and is limited to normally incident, monochromatic waves and a saturated surf zone. Transverse sand bars develop when incident wave height is small or sediment grain size is small (above: shoreline at 0m and break point at ~ 50m).
Crescentic sand bars, with significantly larger spacing than transverse bars, develop when incident wave height or sediment grain size is large (right).



In the latter model (Werner, in preparation), most suitable for modeling evolution of existing sand bars, sand bar patterns are characterized by sand bar crestline position and height and by shoreline position. In this model, crescentic sand bars develop from a linear bar when sediment flux at the bar crest is onshore, with a sufficiently weak cross-shore variation so that onshore bar migration is unstable; a pattern of onshore-directed horns and embayments results, with spacing dictated by an interplay between unstable migration and along-crest smoothing, a reaction-diffusion mechanism (above, right). The shoreline reacts with a mirror-image pattern for wave-dominated onshore surf zone transport (above to the right) or with an offset mirror-image pattern with horns of bars opposite shoreline embayments for offshore current-dominated surf zone transport. These two models are being compared directly to assess the relative strengths and weaknesses of the two modeling approaches.



Extending observations of seafloor bathymetry and subsurface structure beyond the surf zone is an important supplement to detailed nearshore analyses. We conducted a series of tests in Lake Tahoe, California in August 2001, which combined seismic Chirp technology with high-resolution Ocean Bottom Hydrophones (OBHs) in an effort to obtain unprecedented images of shallow sub-bottom stratigraphy. The Chirp instrument, operated by Dr. Neal Driscoll and funded by ONR, collected reflection profiles and was used as a source for recording wide-angle refraction data on an L-Cheapo OBH recording at 16 kHz. Funds from this grant were used to modify four existing L-Cheapo OBHs to be capable of recording at sample rates up to 16 kHz. These higher data rates are critical for recording detailed velocity information from the high-frequency Chirp source. The Chirp instrument, which uses an acoustic, swept-source at frequencies ranging from 2-15 kHz, can be used to image seafloor depth and subsurface features in water depths ranging from a few meters up to nearly a kilometer. The advantage of the Chirp system derives from a bottom penetrating capability (used to image sub-seafloor structure) in combination with high-resolution side-



scan sonar, which enables detailed images of the seafloor. The Chirp system, along with the high-resolution L-Cheapo OBH, can be used on smaller boats for extremely shallow water (<2 m) data acquisition. Dr. Driscoll is moving to Scripps by March 2001 when he will become a tenured Associate Professor. A sample record section of raw data is shown above to the right. While the Chirp system can collect extraordinary time sections, the conversion to depth is critical to understanding the time evolution of the sedimentary sequence. A study of climate variability, for example, requires an understanding of the volumes of sediment associated with a sequence and not simply that the sequences exist. Future experiments will couple the profiling method with GPS technology to allow the location of the towed fish to an accuracy of <10 cm horizontally and vertically. This will allow 3-D volumes to be constructed from the data in absolute spatial coordinates. The time variation of the structure in shallow water near the surf zone will be invaluable to our long-term goals.

IMPACT / APPLICATIONS

The development, implementation and testing of hierarchical complex systems models for nearshore processes permit an assessment of the hierarchical modeling methodology versus Reductionist and Universalist approaches for modeling the nearshore and for modeling other complicated natural systems.

RELATED PROJECTS

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PUBLICATIONS

A. Falques, G. Coco and D. Huntley (2000) A mechanism for the generation of wave driven rhythmic patterns in the surf zone, Journal of Geophysical Research, in press.

G. Coco, D. Huntley, G. Masselink, T. O'Hare and C. Pattiaratchi (2000) Fractal behavior in nearshore processes, Proceedings of the international Conference of Coastal Engineering, Sydney 2000, 1-13.

B.T. Werner and G. Kocurek (1999) Bedform spacing from defect dynamics, Geology, 27, 727-730.

B.T. Werner (1999) Complexity in natural landform patterns, Science, 284, 102-104.

A.B. Murray and G. Reydellet (1999) Rip currents in the absence of bathymetric forcing, Proceedings of the International Association for Hydraulic Research Symposium on River, Coastal and Estuarine Morphodynamics, Genoa, September 6-10, V. 1, 405-414.

B.T. Werner and G. Kocurek (1997) Bedform dynamics: Does the tail wag the dog? Geology, 25, 771-774.

A.B. Murray (1999) From strange attractors to real-world data: evaluating a bedform model by measuring the distance between state-space plots, Journal of Mathematical Geology, in press.

L.B. Clarke and B.T. Werner (2000) Synoptic imaging of nearshore bathymetric patterns, Journal of Geophysical Research, in review.

A.B. Murray and G. Reydellet (2000) A rip current model based on a newly hypothesized interaction between waves and currents, Journal of Coastal Research, submitted.

A.B. Murray (2000) Modeling rip channel development, Journal of Geophysical Research, submitted.

A.B. Murray, M. LeBars and C. Guillon (2000) Tests of a new hypothesis for non-bathymetrically driven rip currents, Journal of Geophysical Research, submitted.